Long-term Carbon Transport and Fuel Retention in Gaps of the Main Toroidal Limiter in TEXTOR

A. Kreter[1], P. Wienhold[1], H.G. Esser[1], A. Litnovsky[1],
V. Philipps[1], K. Sugiyama[2] and TEXTOR team

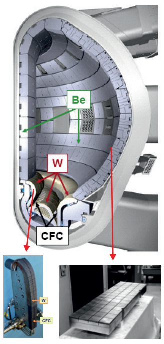
[1] *Institute of Energy and Climate Research - Plasma Physics, Forschungszentrum Jülich GmbH, Association EURATOM-FZJ, Partner In the Trilateral Euregio Cluster, Jülich, Germany*

[2] *Max-Planck-Institut für Plasmaphysik, EURATOM Association, 85748 Garching, Germany*

e-mail: A.Kreter@fz-juelich.de

Introduction

Castellated structures in ITER



All plasma-facing components will be castellated

- Stress release during thermal loads
- Prevention of eddy currents

Issue of fuel retention in gaps

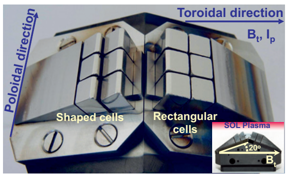
- Wall materials, i.e. carbon, are eroded and transported by plasma
- Materials accumulate in remote areas
- Co-deposition of tritium, i.e. in a-C:T layers
- Gaps are additional remote areas, distributed allover the vessel
- Total area of gaps in ITER ~1000 m^2

→ Potentially large reservoir for tritium

[K. Krieger et al., J. Nucl. Mater. 363-365 (2007) 870]

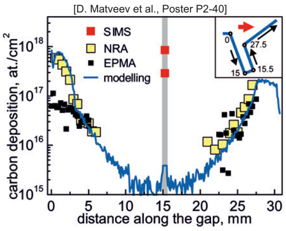
Dedicated experiments and modelling in TEXTOR

[A. Litnovsky et al., J. Nucl. Mater. 15 (2011) S289]



112 s of plasma, ion fluence $2.2\cdot10^{20}$ D^+/cm^2

[D. Matveev et al., Poster P2-40]



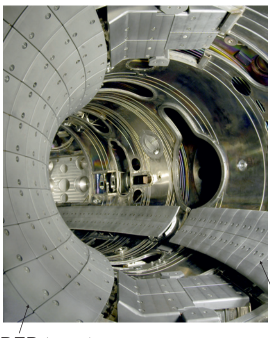
- Carbon deposition in gaps independent of erosion and deposition balance on the top surface
- Deposition higher at the gap entrance, decay length towards bottom ~1 mm
- High deposition on the gap bottom

! Results reflect particular experimental conditions

Aim of this study: Investigate deposition and retention in gaps integrated over a variety of plasma conditions

Experimental

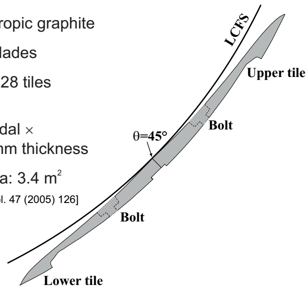
Main toroidal limiter ALT-II



- ALT-II (Advanced Limiter Test II) is the main limiter in TEXTOR
- Material: fine-grain isotropic graphite
- Consists of 8 toroidal blades
- Each blade consists of 28 tiles ordered in two rows
- Tile size: 155 mm poloidal × 100 mm toroidal × 10 mm thickness
- Total ALT-II surface area: 3.4 m^2

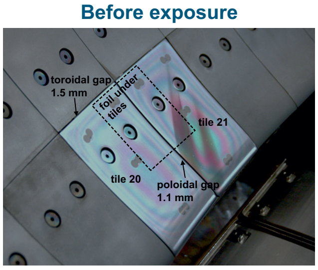
[K.H. Finken et al., Fusion Sci. Technol. 47 (2005) 126]

Poloidal tile shape



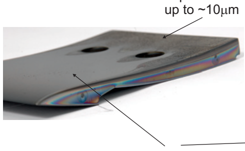
Special ALT-II tiles to investigate deposition in gaps

Before exposure



After exposure (tile 20)

Typical erosion/deposition pattern
[A. Kreter et al., Phys. Scr. T128 (2007) 35]



Tile cut for analysis

Tile preparation

- Plasma facing side and gap sides: polished (R_a ~ 0.1 µm) and coated with Si layer of ≈300 nm (marker)
- Stainless steel foil under tiles 20 and 21 served as gap bottom

Exposure conditions

- Exposed to 9365 s of plasma (one TEXTOR campaign)
- $3\cdot10^{25}$ m^{-2} area-averaged fluence
- 7 boronizations during campaign
- Temperature of top surface up to 400°C, of support structure 150°C

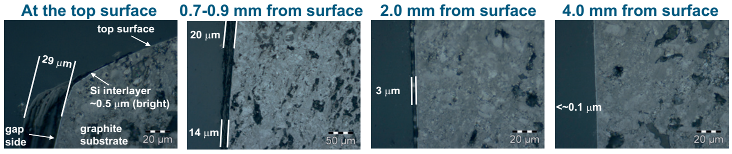
Post-mortem analysis

- Deposition thickness by SEM and microscopy
- SIMS depth profiling
- EPMA for absolute amount of deposition and composition
- NRA/RBS for absolute amount of deposition and composition

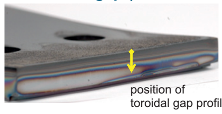
Results and Conclusions

Deposition on side walls of gaps

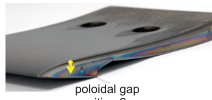
SEM images of tile 21 toroidal gap

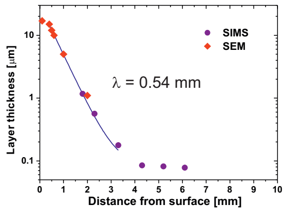


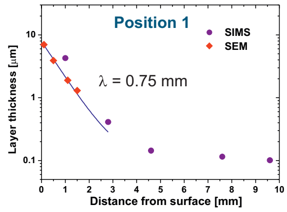
Tile 20 toroidal gap (1.5 mm wide)



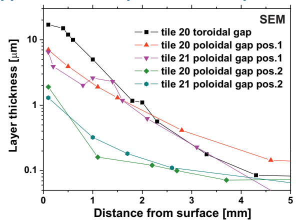
Tile 20 poloidal gap (1.1 mm wide)





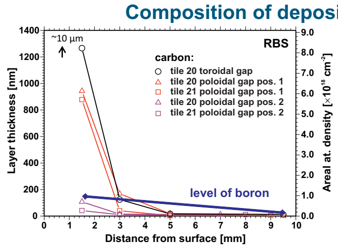


Comparisons: toroidal vs. poloidal; opposite sides of poloidal at two positions



- ✓ Similar measurements done at several positions for toroidal and poloidal gaps of both tiles
- Higher deposition in toroidal than in poloidal gaps (factor of >~2): deeper penetration of B field lines in toroidal gaps + roof-like shaping of limiter poloidally
- Decay lengths vary between 0.5 and 0.9 mm (0.7 mm on average) → Comparable to dedicated experiments despite larger gap width of ALT-II
- Similar deposition on opposite sides of poloidal gap
- Deposition in poloidal gap continuously increases from lower edge of tile towards blade center: higher incident fluxes at the blade center

Composition of deposited layers on side walls



- Deposited layer contains boron from boronizations
- Fraction of boron increases from a few percent at the gap entrance to almost 100% close to bottom
- Virtually no carbon on side wall below 5 mm in gap
- Atomic ratio of oxygen (not shown here) to boron ≈1.5 → Indicates formation of stable oxide B_2O_3 due to gettering
- D/C is 3%-10%, similar to the top surface

Deposition on gap bottom

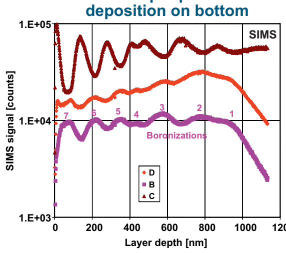
Foil under tiles 20 and 21after exposure

Deposition on gap bottom

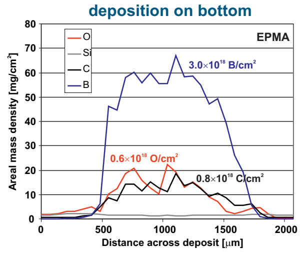
! Measurement for poloidal gap only

- Total deposition thickness 1.1 µm (cf. <0.1 µm on side walls close to bottom)
- Atomic composition: Boron 60 %, Carbon 20%, Oxygen 20%
- Ratio of deposition on bottom to total deposition in gap is 2% for carbon and 30% for boron → Ions reach gap bottom during boronization in glow discharge with higher probability, in accordance with previous investigations [C. Schulz et al., JNM 415 (2011) S781]
- Atomic ratio of oxygen (not shown here) to boron ≈ 0.2
- D/C is ≈30% due to lower temperature than top surface (150°C vs. 400°C)

SIMS depth profile of deposition on bottom



EPMA line scan across deposition on bottom



Trapping efficiency of ALT-II gaps and scaling up for ITER

- Carbon deposition rate in gaps scaled-up to the entire belt limiter (224 tiles): ≈ 8×10^{-5} g/s, 2.8% of the total deposition on the limiter surface
- Fraction of the gap entrance area to the total limiter area: 1.5%

→ **Gaps trap carbon almost double as efficient as top surface**

Estimation for ITER

- Assumption: The same gap trapping efficiency in ITER as for ALT-II in TEXTOR
- Scale up for fraction of gap entrance area to the total limiter area in ITER: ≈10%

→ **Contribution of gaps to total deposition in ITER ≈ 20%**

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